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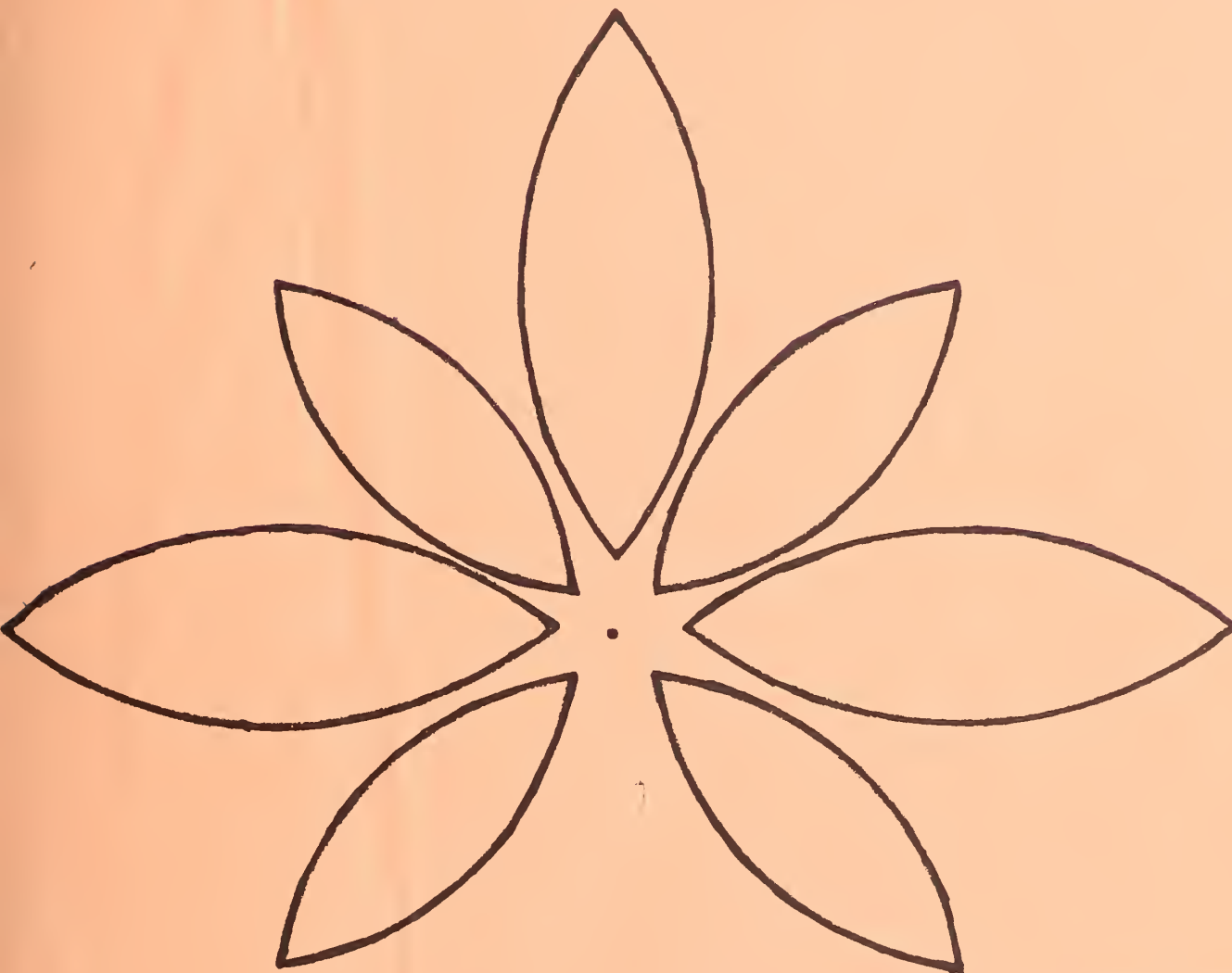
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THE AWAKENING FREEZE-DRYING INDUSTRY //



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C & R-PREP.

by  
Kermit Bird

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UNITED STATES DEPARTMENT OF AGRICULTURE  
Economic Research Service,  
Marketing Economics Division  
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January 1965 //



## UNITED STATES DEPARTMENT OF AGRICULTURE

Economic Research Service

Marketing Economics Division

Washington, D. C., 20250

THE AWAKENING FREEZE-DRYING INDUSTRY; 1/

by Kermit Bird

The title implies that freeze-drying has been taking a nap and is not blossoming forth as it should. Some people experienced in food processing feel that way. However, I agree with the Persian poet:

Awake, for morning in the bowl of night  
Has flung the stone that put the stars to flight,  
And lo, the hunter of the east has caught  
The sultan's turret in a noose of light. 2/

At the recent International Freeze-Drying Course (July 1964) I detected undertones of pessimism concerning future prospects for the food freeze-drying industry. Some were mentally paraphrasing the old expression, "If you're so smart, why ain't you rich?" into "If freeze-drying is so good why isn't it developing faster?" Let's ask some pertinent questions and try to supply the needed answers.

- \* Is food freeze-drying developing at a normal rate when we compare its growth with other new foods in their initial stages?
- \* If the industry has come to a slowing down period, what's been keeping it from moving forward?
- \* Or, if it is moving along in a normal manner, what is its future growth potential?

First, we shall look at where freeze-drying now is, and discuss some newly developed foods. Then, we compare freeze-drying with several other processed foods in their initial growth stages. For this comparison we shall use frozen foods, soluble coffee, and processed potatoes. From the growth curves experienced by these foods we may learn whether freeze-drying's growth is normal or lagging.

Present Status of the Freeze-Drying Industry

In the U. S., freeze-drying changes occur rapidly. Estimates of industry volumes are scarce and even the exact number of plants in operation is uncertain. At present, 19 American, 2 Canadian and 1 Mexican plant process freeze-dried foods. Several are under construction and others are being

1/ Prepared for presentation to the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. semiannual meeting, Jan. 25-28, 1965, Chicago, Illinois. See last page of text for reprint information.

2/ Khayyam, Omar. The Rubiat, Stanza 1, Fitzgerald's 1st ed.



considered. In Europe there are 27, and in the rest of the world there are about 8 processors.

Main products, now inducing new investment are coffee, berries, fruits, and mushrooms. Large volume foods at present are chicken, beef, mushrooms, shellfish, pork, vegetables, and fruit.

Volume of foods freeze-dried in the U. S. were about 25 million pounds (frozen input) for 1964. This compares with my estimate of 11.3 million in 1963, and 5.6 million pounds in 1962. Table 1 shows sizes of firms engaged in the industry and the industry size as of January 1965.

Table 1. --United States and Canadian firms freeze-drying food for commercial market, January 1965.

Firm:	Number and size of:	Total shelf	Wet product:	Drying cycles:	Maximum
:	cabinets	area of plant:	per sq. ft.:	per 24-hour	product
:	:	:	:	day	:per day
:	<u>Number &amp; sq. ft.</u>	<u>Sq. ft.</u>	<u>Lbs.</u>	<u>Number</u>	<u>Lbs.</u>
A	: 1-685	: 685	: 2.5	: 2.0	: 3,425
B	: 2-100, 2-250, 5-650	: 3,950	: 2.5	: 2.4	: 23,700
C	: 1-128	: 128	: 4.0	: 1.0	: 512
D	: 1-500, 1-1,000	: 1,500	: 2.5	: 2.4	: 9,000
E	: 6-400	: 2,400	: 2.5	: 3.0	: 18,000
F	: 2-2,000	: 4,400	: 2.6	: 2.4	: 27,456
G	: 1-500	: 500	: 2.5	: 3.0	: 3,750
H	: 1-500	: 500	: 2.5	: 2.0	: 2,500
I	: 6-300	: 1,800	: 2.5	: 2.0	: 9,000
J	: 8-500	: 4,000	: 2.5	: 2.5	: 25,000
K	: 2-100	: 200	: 2.5	: 2.5	: 1,250
L	: 1-200, 1-200	: 400	: 2.8	: 3.0	: 3,360
M	: 1-150	: 150	: 2.0	: 2.0	: 600
N	: 10-1,100	: 11,000	: 1.38	: 3.0	: 44,110
O	: 12-1,000	: 12,000	: 2.0	: 2.0	: 48,000
P	: 4-1,000	: 4,000	: 2.5	: 2.0	: 20,000
Q	: 1-1,000	: 1,000	: 2.5	: 2.0	: 5,000
R	: 1-1,100	: 1,100	: 1.8	: 3.0	: 5,940
S	: 4-400	: 1,600	: 2.5	: 2.4	: 9,600
T	: 2-340, 4-340,	:	:	:	:
	: 1-340, 4-500	: 4,380	: 3.0	: 3.0	: 39,420
U	: 3-250	: 750	: 2.5	: 2.4	: 4,500
Total Industry		57,643			304,123



Note on accuracy of data: Number of cabinets and square feet of shelf area per cabinet are quite accurate. Probably total shelf area of the industry, 57,643 square feet, is accurate within 2 percent. Product per square foot of shelf area and drying cycles per day have less validity. These figures are subjective judgements of how each plant is operating. Hence, the last column, maximum product per day, is less accurate. If the inaccuracies have no particular bias they may tend to balance out and for the total industry figure we predict a higher degree of accuracy than for individual firms. The total industry figure of 304,123 pounds of wet product per day is estimated to be accurate within 8 percent. Thus, the true figure for the capacity of the industry may be in the range of 280,000 to 328,000 pounds of wet product dried per day.

Companies listed in table 1 are the freeze-dry food processing plants of America and Canada. Several of those listed have not yet started operating, but they will be processing food in a short time. Two or three of the plants included have undergone extensive plant additions within the past year. Ranging in size from 128 to 12,000 square feet of drying shelf area, their output varies from  $\frac{1}{4}$  ton to 24 tons per day, wet weight. The 21 plants now processing freeze-dried foods have a total of 57,643 square feet of drying shelf area. If our loading practices and cycle-time estimates are correct, their daily capacity is about 304,123 pounds of frozen food.

If during 1965 the freeze-drying industry were to operate at its daily capacity for 175 days, output for the year would be 53 million pounds, wet weight. Operated 200 days, the 1965 yearly output would be 61 million pounds. Our volume prediction for 1965 is 50 million pounds. If new plants are built and existing plants enlarged during the year, processing capacities will be greater. If markets are found for increased use of freeze-dried products, it is possible that the food freeze-drying processing industry will exceed the 50 million pound prediction.

In an industry such as freeze-drying, with its high fixed costs, it is economical to operate as many hours per year as possible. This is especially true in this case where the fixed cost item is equipment having a high obsolescence rate.

#### Future Aspects of Freeze-Drying

My observations of the future of the industry are based partly on products currently being developed or now being market tested. Three brands of freeze-dried coffee are being market tested in the United States. Freeze-dried soluble coffee is sold commercially in Canada, England, Germany and Italy. Success of this new beverage can radically change the stance of both the soluble coffee and freeze-drying industries. Future sales of freeze-dried soluble coffee depends to a large degree on its palatability and processing costs relative to the competitive spray-dried coffee. My untrained palate can detect little discernible differences between the new freeze-dried and the old spray-dried soluble product. However, coffee palatability is extremely difficult for nonexperts to judge since many important variables other than the drying method determine coffee flavor. Country of origin,

year grown, variety and grade of bean, storage conditions, method and percent of extraction, additives, package, and packing method are important.

I have no information on processing costs of freeze-dried coffee. An offhand guess would place costs at a level of 4 to 6 cents per pound of water removed. This is considerably higher than for spray-drying. Whether improved palatability of freeze-dried soluble coffee offsets its higher water extraction cost is a million dollar question in today's freeze-drying and soluble coffee industries.

Freeze-dried tea is not yet on sale in America. The English freeze-dried tea now being marketed through vending machines is excellent, and should have a market acceptance here. Is freeze-dried tea enough better than vacuum-dried tea now being produced to justify the added sublimation expense? This is another unanswered question of importance to the freeze-drying industry.

Peaches, strawberries, and blueberries have been market tested in breakfast cereals. These fruit products are interesting to the public, and I predict a firm future for this market use of freeze-dehydrated fruits. Bananas, cherries, raspberries, and apricots may be freeze-dried and usable in the same way. Fruits and berries dried in the form of powders or granules may be used in mixtures with other foods, and fruits may have the largest growth of any food group. Some vegetables as tomatoes may be used in a similar manner.

Abroad, several companies market a wide variety of vegetables, seafood, dairy products, and meats. Freeze-dried seafoods, other than shrimp and crab have not yet been introduced to American consumers. Three U. S. based companies now are market testing lines of prepared dinner-type entrees. Items include shrimp creole, shrimp and crabmeat cutlet, crab newburg, chicken tetrazzini, and chicken a la king. Other firms are developing similar prepared items for retail sale. Quality of these prepared items seems to vary with the processor, the individual item, and even among samples of the same item. Quality control seems lacking. This is characteristic of new products, though, and should not be of primary concern during the market test stage.

West Coast chives on the retail market may be the forerunner of other flavorings, spices, and extracts. One of the more exotic products in the developmental stage is freeze-dried ice cream. It may be used as a confection since it is delightful to eat in the dry state. If chocolate or candy coated to prevent rehydration, it should make a hit with kids. This is true if my own children may be used as an unbiased sample.

Recently or nearly completed plants in Pennsylvania, California, Michigan, Mexico, New Zealand, Germany and China are designed to handle a wide variety of seafoods, meats, mushrooms, dairy foods, fruits and vegetables. These products will be the important ones in the freeze-drying industry of tomorrow. Other new plants are specialized for one product only. Information from Japan points toward several new and



interesting freeze-dried foods. One is soybean paste. Another is a food made from chlorella, an algae containing high-quality protein and B-complex vitamins. 3/

### Comparison of Freeze-Drying's Growth with Several New Products

In examining the potential of the food freeze-drying industry, we assess its future by analyzing growth patterns of other foods that have been successful. We compare freeze-drying's growth with the growth of these other newly-developed foods. Our projections are based on past growth of "successfully introduced" new foods.

We make the implied assumption that freeze-drying will be a "success". In view of the growth of the industry during the past several years, we expect growth to continue.

Frozen foods have interesting growth patterns. They vary with the particular frozen food or type of frozen food you analyze. Figure 1 shows frozen meat and fish volumes have grown steadily over a long period of years at a slow, nonspectacular rate. Speciality items came along later and had rapid advances. Concentrates, poultry, and vegetables also grew rapidly during the years studied. Table 2 shows production figures for various frozen food categories.

Table 2. --Growth of commercial frozen foods

	: Fruits :	:Vege- :tables:	: Poultry :	: Meats :	: Sea : foods :	: Prepared :specialities:	:Concen- :trates :	:Total frozen : foods 2/
	-billion pounds-							
1939	: .2	: .1	: 1/	: 1/	: .1	: 1/	: 1/	: .3
1944	: .3	: .3	: .1	: 1/	: .1	: 1/	: 1/	: .8
1949	: .4	: .6	: .2	: .1	: .2	: 1/	: .1	: 1.5
1954	: .5	: .9	: .5	: .2	: .4	: .3	: .8	: 3.7
1959	: .6	: 1.6	: 1.7	: .3	: .5	: .7	: 1.1	: 6.6
1962	: .7	: 2.3	: 2.2	: .5	: .6	: 1.2	: 1.8	: 9.1

1/ Less than .1 billion pounds.

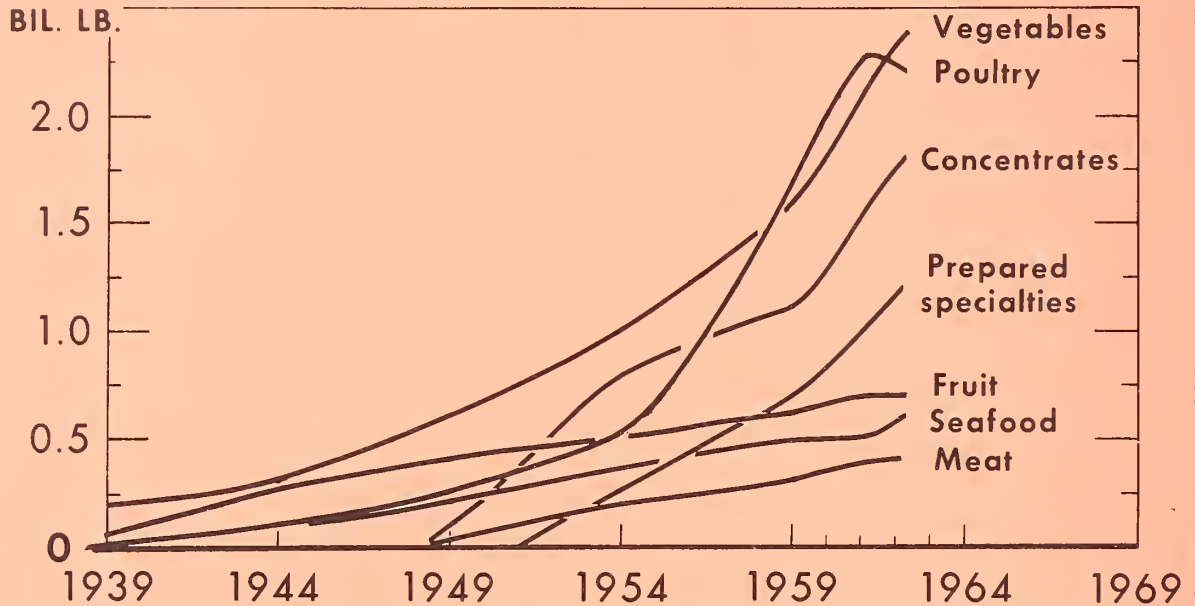
2/ Because of rounding, individual product figures may not add to total.

Sources: National Ass'n of Frozen Food Packers, USDA, Fish and Wildlife Service, Florida Citrus Commission, and Quick Frozen Foods.

Two other successful introductions on the U. S. market have been processed potatoes and soluble coffee. We should keep in mind that for every successful innovation such as these two, there have probably been a hundred "failures". Growth curves of these two foods are shown in figure 2. They show that even a successful new food is fairly slow in

3/ From personal conversation with Akira Takagi of Mitsui & Co. Ltd. and Shin Shimizu, Daiichi Raizo Co., Ltd., Tokyo, Japan.

## PRODUCTION OF COMMERCIAL FROZEN FOODS



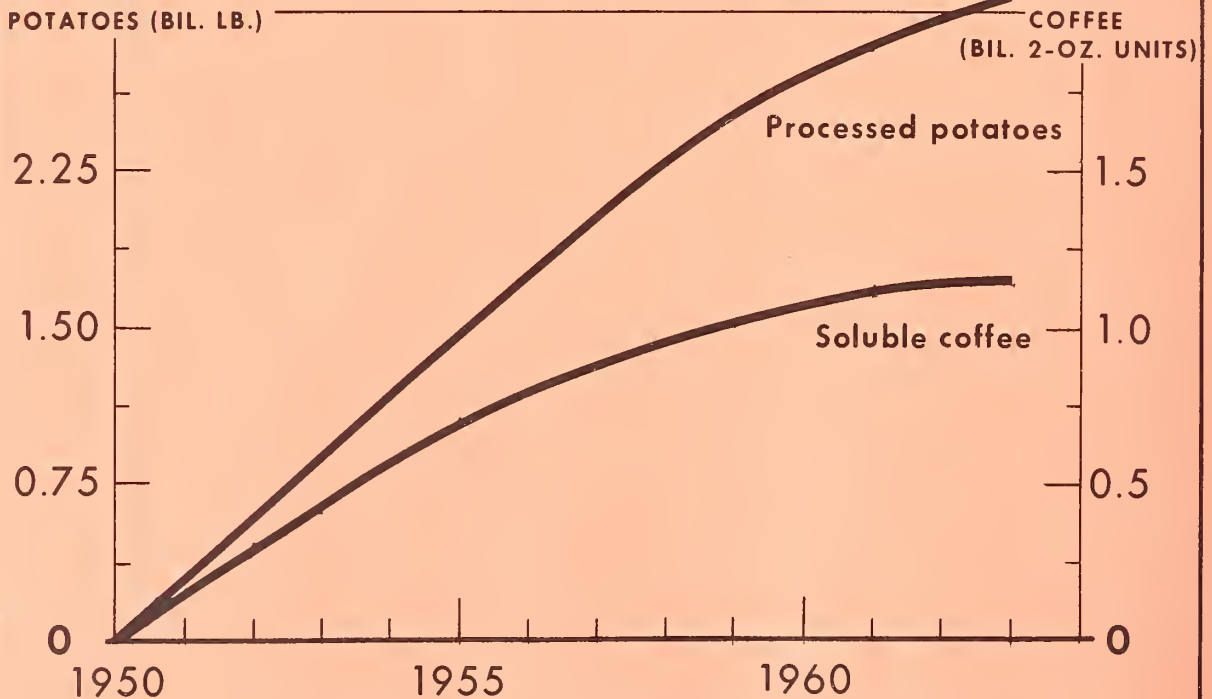
SOURCE: NATIONAL ASSOCIATION OF FROZEN FOOD PACKERS, U.S.D.I., FISH AND WILDLIFE SERVICE, FLORIDA CITRUS COMMISSION, QUICK FROZEN FOODS.

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NEG. ERS 3262-64 (10) ECONOMIC RESEARCH SERVICE

Figure 1

## PROCESSED POTATO AND COFFEE PRODUCTION



SOURCE: NATIONAL POTATO COUNCIL AND PAN AMERICAN COFFEE BUREAU.

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Figure 2

getting started. But volumes increase rapidly as it is accepted in the market. If the food follows a normal pattern, volumes taper off after 8-12 years. Soluble coffee appears to have reached a plateau of sales in about 1961 or 1962. Perhaps the newly developed, freeze-dried coffee now being market tested is an attempt to keep the growth of the industry moving forward. Volume increases of processed potatoes have been equally striking and follow a similar pattern. We are just entering the plateau. Table 3 shows growth of processed potatoes and table 4 shows growth for soluble coffee. In both foods, the tapering-off period came after about 12 years of rapid expansion.

Table 3. --Growth of processed potato industry

Year	Annual production <u>1/</u>
	-Billion pounds-
1951	: .35
1952	: .27
1953	: .43
1954	: .44
1955	: .79
1956	: .92
1957	: 1.03
1958	: 1.82
1959	: 2.25
1960	: 2.82
1961	: 2.95
1962	: 3.09
1963	: 3.26
	:

1/ Includes potatoes dehydrated, hash, stews, soups, and frozen prepared items.

Source: National Potato Council.

Table 5 shows average annual growth of the 6 food groups we have been discussing. The time period selected is during their initial rapid growth phases. Here we see that frozen vegetables and soluble coffee experienced a 26 percent growth each year. Frozen concentrates and processed potatoes had growths of 34 and 36 percent, respectively. Frozen poultry products had a 46-percent growth. Frozen prepared specialties grew at an average rate of 63.2 percent over the preceding year, from 1949 to 1962. Three levels of growth, 30.5 percent, 46 percent, and 63.2 percent later are used to estimate volume growth of freeze-dried foods.



Table 4. --Growth of United States soluble coffee industry 1/

	:Bags roasted for :soluble coffee <u>2/</u>	:Cups per :person :per day	:Equivalent <u>3/</u> :2 ounce units	:Soluble as percent of :total coffee consumption
	: :Thousands	: :Number	: :Millions	: :Percent
1951	: 771	: N.A.	: 227	: N.A.
1952	: N.A.	: N.A.	: 286	: N.A.
1953	: N.A.	: .30	: 383	: 11.5
1954	: 2,052	: .37	: 555	: 13.9
1955	: 2,323	: .46	: 651	: 17.2
1956	: 3,140	: .50	: 770	: 17.7
1957	: 3,336	: .55	: 930	: 19.2
1958	: 3,492	: .60	: 988	: 20.4
1959	: 3,744	: .56	: 1,044	: 20.2
1960	: 3,999	: .64	: 1,098	: 21.5
1961	: 4,010	: .67	: 1,172	: 21.5
1962	: 4,082	: .65	: 1,211	: 21.6
1963	: 3,934	: .61	: 1,181	: 21.0

1/ Source: Annual Coffee Statistics, various years, Pan American Coffee Bureau.

2/ A bag of coffee weighs 132.276 pounds or 60 kilos.

3/ From 1951 to 1961 the Pan-American Coffee Bureau used a unit of soluble coffee as 27.8 percent of green coffee and 33.3 percent of a unit of roasted coffee. Currently they use a ratio of soluble to green coffee as 33 1/3 percent. This reflects increased extraction rate resulting from technological improvements.

Table 5. --Growth rates of new foods during their initial fast growth periods

Food	: : Years observed :	: : Average annual rate : of gain : Percent over previous : year
Frozen vegetables	: 1939 to 1962	: 25.6
Soluble coffee	: 1951 to 1960	: 26.4
Frozen concentrates	: 1949 to 1962	: 34.0
Processed potatoes	: 1952 to 1960	: 36.0
Frozen poultry	: 1939 to 1962	: 46.0
Frozen prepared specialities	: 1949 to 1962	: 63.2

#### The Future of Freeze-Dried Foods

United States freeze-drying production for 1964 was obtained from production estimates similar to those in table 1. Our estimate for 1964 is 29,000 square feet of shelf area. Plants in business during most of



the year averaged about  $2\frac{1}{2}$  pounds of wet product per square foot of shelf area and 2 drying cycles per day. This resulted in 145,000 wet pounds per day production. If the plants operated 175 days per year, the 1964 yearly production was about 25 million wet pounds. This 25-million pound figure was the one used for further projecting into the future. The 1965 volume projection is 50 million pounds, using similar estimating techniques.

Figure 3 shows several growth curves of freeze-dried foods. They differ, depending on what they were compared with. The "A" curve shows expected growth of food freeze-drying if it were to follow the growth experienced by frozen specialties, 63.2 percent per year. If freeze-dry processing increases at this annual rate, 1970 volumes may be 415 million pounds. If most of the current products now being market tested are successful, this figure may be conservative.

"B" curve, shown in figure 3, is expected growth of freeze-drying if it increases at the same percentage rate as the one experienced by frozen poultry. Each year was 46 percent higher than the previous years figure. If food freeze-drying averages such a growth, 1970 would be a 242-million pound year. This appears to be a reasonable growth curve if about half the products now being market tested are successful.

"C" curve, also shown in figure 3, is one derived from the growth pattern of 4 other newly introduced foods averaging 30.5 percent gain. These foods were soluble coffee, frozen vegetables, frozen concentrates, and processed potatoes. If freeze-drying were to grow at the average rate of these 4 foods during their rapid growth periods, it would have volume of about 125 million pounds by 1970. This curve presents a pessimistic picture of the future of the industry and assumes few new products will enter the market stream.

Curve "D", shown in figure 3, is another estimate of freeze-drying volumes. Curves A, B, and C used an average percentage rate of growth which was constant over the period. This is not quite the way a new product or new process grows. During the first few years a new product is put on the market, percentage growth is phenomenally high, although absolute volumes are small. As a neophyte product achieves acceptance, the percentage growth from the previous year decreases as absolute volume increases. (A problem is to ascertain where freeze-drying now is in its growth pattern and for this analysis I have assumed the industry is about 3 years of age). For curve "D", a 100-percent rate of increase is used for 1964 to 1965. For 1965 to 1966, the rate is 75 percent; 1966 to 1967 has a 56-percent rate; 1968, 1969, and 1970 have expected growth rates of 42, 32, and 24 percent, respectively. The anticipated volume for 1970 is 317 million pounds per year. Curve "D" is my personal estimate for the U. S. food freeze-drying industry, using

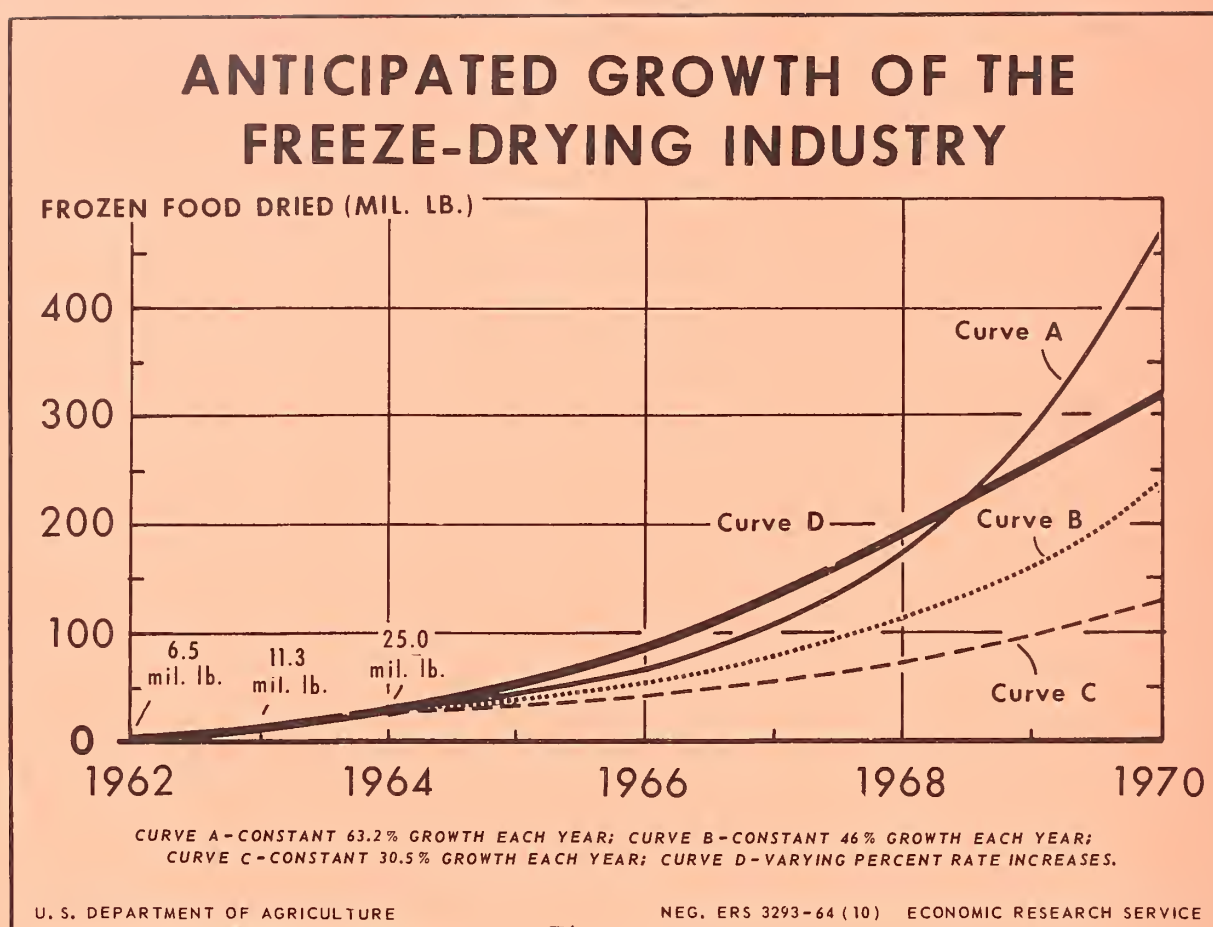


Figure 3

this new product comparison method. 4/

4/ It is interesting to compare this estimate with one made by me last year using an entirely different procedure for estimating future volumes. See Bird, Kermit. "The Freeze-Drying Industry: Projections of Capital and Labor Requirements 1963-1970", U. S. Department of Agriculture (speech given at the Philadelphia chapter ASHRAE meeting, April 9, 1964, 9 pp).

In this April 1964 estimate, volumes were expected to be about 250 million lbs. annually in 1970. Briefly, the process was to examine each freeze-dried food as to its future potential. A subjective percentage rate was applied to each food, relative to its expected percentage in the total food processing volume for that food. These expected freeze-dried volumes were added up and the total freeze-drying volume was 250 million pounds.



Will Freeze-Drying Hurt the Freezing Industry?

Many persons who have investments in freezing or cold storage facilities are concerned that freeze-dried foods may drive frozen foods out of the market. I do not think this is the case. If freeze-drying brings about any changes in the freezing industry, they will be favorable ones. Here's my thinking on this subject. Freeze-dried foods are not of a comparable quality with frozen foods. This is a generalization and I recognize that some particular freeze-dried items may be just as good as or even superior to frozen items. It's hard for me to imagine, though, how an item that started frozen, and then went through an 8-to-10 hour drying cycle could be superior to the product it started as. Palatability tests we have conducted bear this out--freeze-dried foods are good when compared with other dried foods but are generally inferior to frozen ones. 5/

Freeze-dried foods should improve business for the freezing industry. Every hundredweight of freeze-dried food uses frozen foods as raw material. Since freeze-dried foods substitute for other dried foods, rather than for frozen foods, the freezing industry can benefit from doing part of the processing for the dried food industry. Since it requires about 1.5 to 1.8 tons of refrigeration to freeze 100 pounds of food per hour, the present freezing requirements of the freeze-drying industry are only about 25 tons of refrigeration. In 1970, however, freezing of freeze-dried foods may require 300 tons of refrigeration. Sublimation also requires refrigeration (assuming vacuum pumps with a mechanical refrigeration system rather than steam jet pumps are used). Required amount of refrigeration for sublimation varies with the product, percent moisture of the food being dried, size of installation, and temperatures of the condenser. Refrigeration requirements may vary from a low of about 5.5 tons to a high of about 10 tons of refrigeration needed per 100 pounds of ice sublimated per hour. For our example, let us assume 8 tons of refrigeration were needed for each 100 pounds of ice sublimated. Present requirements (25 million pounds per year, wet product weight, averaging about 70 percent moisture) would be about 300 tons of refrigeration. In 1970, the industry may need an additional 3600 tons of refrigeration to sublimate the ice of the foods being freeze-dried. Clearly, it is to the advantage of a food freezer to encourage the freeze-drying industry in its growth.

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5/ Bird, Kermit. Freeze-Dried Foods: Palatability Tests, MRR-617, U. S. Department of Agriculture, July 1963, 36 pp. Also Bird, Kermit. "Palatability of Freeze-Dried Meats", (speech given at International Freeze-Drying Course, Lyon, France, July 1964, 16 pp.) Both of the above publications are available from: Division of Information, OMS, U. S. Department of Agriculture, Washington, D. C., 20250.

### Summary of Growth Prospects

There are now occurring and in the future there will be significant developments in dehydration and other methods of food processing. 6/ Dried foods of tomorrow will include those dried by the best means available, taking into consideration costs, quality, investment needed, capital already invested, and specific end uses of the foods. Freeze-drying, an important and interesting drying method, will fill a vital role in the production of high-quality dried foods.

A pressing need is for lower freeze-dry processing costs. Cost reductions will come as specialized items of equipment are designed and put to use. Machines able to handle liquids or small solid particles will be marketed. Heat input and water evacuation methods will surely improve. I predict cycle times of 3 to 5 hours on a regular basis. Food preparation, materials-handling, and container-filling operations are other areas where costs can be lowered. Changes of attitude about freeze-drying will help. Quality standards of freeze-dried foods need to be maintained. This is especially important in a new industry. To achieve the best final product, new varieties and improved freezing methods need to be developed--tailored for their specific end use.

Yes, freeze-drying is growing in a normal manner. This is evident when we compare its future with other new foods that have been successes on the market. New foods expand rapidly after their initial developmental period. Thus, freeze-drying needs to gird for the rapid expansion period ahead. Masfield expressed it: 7/

"All the great things of life are swiftly done,  
Creation, death, and love the double gates.  
However much we dawdle in the sun,  
We have to hurry at the touch of Fate;  
When life knocks at the door, no one can wait."

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6/ An excellent article that develops this theme is Mottern, H. H. and Johnson, A. H., "Fifty Years of New Product Development", Food Technology, Sept. 1964, 4 pp. Free reprints of this article are available from: Dr. A. H. Johnson, National Dairy Corp., 801 Waukegan Road, Glenview, Illinois.

7/ Masfield, John. The Widow in the Bye Street. Part 2, 1912

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- 185 -

The U. S. Department of Agriculture has published other reports on freeze-drying of foods. These are free, while our supply lasts, although some are limited one per person.

Selected Writings on Freeze-Drying, ERS-147, Jan 1964, 53 pp, (A collection of previously published articles and speeches).

Freeze-Drying of Foods -- A Look into the Future, ERS-134, Aug. 1963 7 pp. (Included in Selected Writings on Freeze-Drying, listed above).

Freeze-Drying of Foods: Cost Projections, MRR-609, Jan 1964, 34 pp.

Freeze-Dried Foods: Palatability Tests, MRR-617, July 1963, 36 pp. (Limit of one per person).

Freeze-Drying of Foods: A List of Selected References (an annotated bibliography) LL-77, July 1963, 79 pp, (Limit of one per person).

Freeze-Drying Citations (Mimeo list of freeze-drying literature references) Feb. 1964, 6 pp.

The Freeze-Drying Industry: Projections of Capital and Labor Requirements, 1963-70 (Speech reprint) April 1964, 9 pp.

Designing a Freeze-Drying Plant -- Some Economic Considerations, (Speech reprint) Mar. 1964, 8 pp.

Freeze-Dried Foods and Tomorrow's Consumer (Speech reprint) July 1964, 4 pp.

Freeze-Dried Foods Will Land on Moon but Industry Jobs Won't Orbit, (Article in July 1964 issue of Farm Index), 1 pp.

Freeze-Drying Fable for Fifth Graders, (Speech reprint) Oct. 1963, 2 pp.

Palatability of Freeze-Dried Meats (Speech reprint) July 1964, 16 pp.

Freeze-Drying Attitudes (Contains a 1964 Directory), (Speech reprint), Dec. 1964, 13 pp.

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